UNIT 4: INTRODUCTION TO RADIOACTIVE MATERIALS

LEARNING OBJECTIVES

By the end of this section, participants will be able to:

- Describe the sources of radiation
- List at least five uses of radioactive materials
- Define radioactive terms
- Explain the basic principles of radiation
- Describe the health effects of radiation exposure and protective methods

INTRODUCTION

Your jurisdiction is located at or near a Department of Energy (DOE) site or transportation route. DOE has developed comprehensive transportation and disposal plans designed to help prevent radiological accidents. Transportation of radioactive materials is well-regulated and very safe. Consequently, your chances of responding to such incidents are minimal.

Highway incident involving radioactive materials

However, you need to be prepared for all types of emergencies. So while this program covers all categories of hazardous materials and related safety and health issues, there is a special focus on radioactive hazards.

Background Radiation

Most of the 92 naturally occurring elements on earth are unstable and can change into other forms. Radiation begins in the center of the nucleus of these elements, where energetic parties or waves of energy are released as the atoms decay to stable forms.

More than 80% of the radiation we are exposed to comes from “background” radiation — natural sources like sunlight, soil and rocks. Most remaining exposures come from manmade sources, such as x-rays and common household appliances like smoke detectors and color televisions.

On the following page, Table 4.1 shows the average annual dose from natural background. Table 4.2 shows the average annual dose from manmade sources.

Table 4.1	
Source	**mrem/year**
Cosmic rays (radiation from the sun and outer space)	**28**
The earth	**26**
Radon (in certain geographic areas)	**200**
The human body	**25**
Building materials	**4**

Table 4.2	
Source	**mrem/year**
Medical (primarily from diagnostic x-rays)	**90**
Fallout from atomic weapons	**5**
Consumer products (color television, computers)	**1**
Nuclear power	**0.3**

Exposure to radiation is generally measured in rems**.** Most human exposure is so small the dose can be measured in millirems. The average person's exposure is about 360 millirems a year, about 300 of which is from background radiation. An airplane trip across the country adds about 5 millirems, dental x-rays about 40 millirems. A person living just outside a nuclear power plant receives another millirem or so each year, while an employee of the same plant receives an additional 300 millirems or so per year.

How Radioactive Materials Are Used

Radioactive materials are used in producing many of the products we use every day: plastic wrap, radial tires, coffee filters, and smoke detectors.

Many medical facilities contain radioactive hazards.

Radioactive materials are used for diagnostic radiology, radiation medicine, and radiopharmaceuticals. Radiation hazards also exist wherever radioactive materials are stored or radioactive waste products are discarded.

Fires involving radioactive materials can result in widespread contamination. Radioactive particles can be carried easily by smoke plumes, ventilation systems, and contaminated water runoff. While radiation exposure outside of medical and research facilities is not common, you should be alert to its presence in labs, hospitals, and other treatment facilities.

Table 4.3 lists some commonly-used radioisotopes, examples of their uses, the forms in which they're transported, and the most common mode of transport.

TABLE 4.3 RADIOISOTOPES USED IN MEDICINE AND INDUSTRY

RADIOISOTOPE	EXAMPLES OF USES	FORM FOR SHIPPING	MODE OF TRANSPORT
AMERICIUM 241	Used in industry to: • Determine drilling locations for oil wells • Manufacture home smoke detectors • Measure lead in dried paint • Ensure uniformity in steel and paper production	Powder (enclosed in capsule)	Highway Rail Air
CALIFORNIUM 252	Used in medicine to: • Research and treat cancer (especially cervical, ovarian, and brain cancers) Used in industry to: • Detect explosives in luggage at airports • Measure moisture in soil and silos • Start up nuclear reactors	Solid	Highway Air
COBALT 60	Used in medicine to: • Treat cancer • Suppress immune reaction in transplants • Sterilize surgical instruments Used in industry to: • Test welds and casting • Check for internal structural flaws • Locate buried utility conduits Used in agriculture to: • Preserve poultry, fruits and spices	Solid	Highway Rail Air
IODINE 131	Used in medicine to: • Diagnose and treat medical disorders • Trace medical observations	Liquid	Highway Rail Air
IRIDIUM 192	Used in medicine to: • Treat prostate cancer Used in industry to: • Check the integrity of pipeline welds, boilers and aircraft parts	Solid	Highway Air
PLUTONIUM 238	Used in medicine to: • Power pacemakers	Solid	Highway Air
HYDROGEN 3 (TRITIUM)	Used in industry to: • Illuminate paint, exit signs and aircraft • Trace the flow of water • Identify molecules in scientific studies	Solid	Highway Rail

RADIOLOGICAL TERMS

In order to understand radiological hazards, you should first become familiar with some related terms:

Curie is a measurement of the activity of an isotope.

Rad (radiation absorbed dose) measures a quantity called "absorbed dose," which means the amount of energy actually absorbed in a material. The rad measures any type of radiation, but it does not describe the biological effects.

Rem (roentgen equivalent man) measures a quantity called "dose equivalent," which relates the absorbed dose in human tissue to the resulting biological damage. This measurement is necessary because not all radiation has the same biological effect. The rem measurement is obtained by multiplying the rad by a quality factor that is unique to a specific type of radiation.

Roentgen (R) measures the quantity of an exposure to a gamma or x-ray.

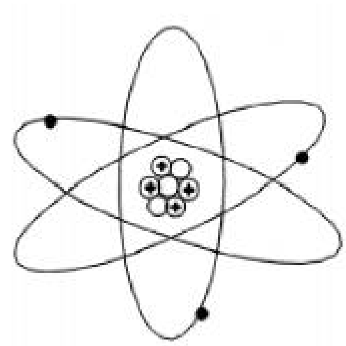
The terms above reflect traditional units of measuring radiation. However, SI (Systeme International) units are now being accepted in the U.S. The following table shows each traditional unit, the comparable SI unit, and the conversion factor from the smaller amount to the larger.

Traditional Unit	SI Unit	Conversion Factor (smaller unit to larger unit)
Curie (Ci)	Becquerel (Bq)	1 Ci = 37 billion Bq
rad	Gray (Gy)	1 Gy = 100 rad
rem	Sievert (Sv)	1Sv = 100 rem
Roentgen (R)	Coulombs per kilogram (C/kg)	1 C/kg = 3,876 R

For the purposes of this program, and for your response, you can assume all these terms mean essentially the same thing: a unit of measure of radiation.

Basic Principles of Radiation

The atom is a unit of matter. The three basic particles of the atom are protons, neutrons, and electrons. Each atom has a center called a **nucleus.** The nucleus contains protons, which carry a positive electrical charge, and neutrons, which are not charged. Negatively-charged electrons orbit the nucleus. Electrons are much lighter than protons and neutrons; 1,845 electrons have the mass of one proton.



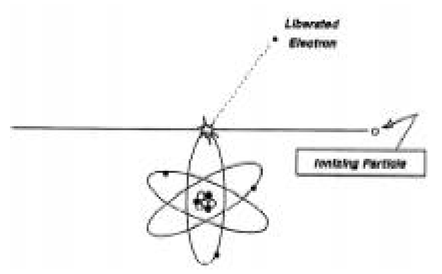
Parts of an Atom

The positive protons and the negative electrons hold the atom together. When there are equal numbers of protons and electrons, the charges are balanced and the atom is stable.

Atoms of the same element have the same number of protons, but can have a different number of neutrons. Atoms that have the same number of protons but different numbers of neutrons are called **isotopes.** Isotopes have the same chemical properties; however, the nuclear properties can be quite different.

If there are too many or too few neutrons for a given number of protons, the nucleus will have too much energy and the atom will not be stable. The atom will try to become stable by giving off excess energy in the form of particles or waves (radiation). When we talk about radiation, we are usually referring to **ionizing** radiation rather than non-ionizing radiation.

Ionizing radiation has a tremendous amount of energy. When an ionizing particle interacts with an atom, it can remove an electron from the atom’s orbit, causing the atom to become charged, or ionized.



Ionization

Non-ionizing radiation does not ionize the atoms around it. Most background radiation from the soil, for instance, does not ionize the atoms it contacts.

The type of radiation given off by the nucleus depends on how the nucleus changes. If protons and neutrons are rearranged, the atom emits gamma radiation. If an orbiting electron changes, the atom gives off x-rays. If the number of protons and neutrons changes, the atom emits one or more types of radiation.

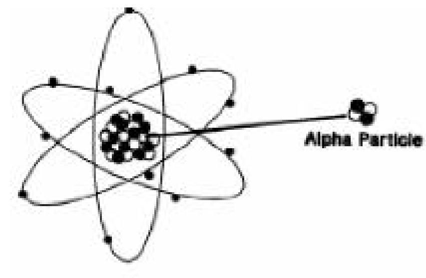
Types of Radiation

There are several types of radiation present in nature and manmade sources:

- Alpha particles
- Beta particles
- Gamma rays
- X-rays
- Neutrons

Alpha Particles

Alpha particles are the slowest of the three types of radiation. They can travel only a few inches in the air, losing their energy almost as soon as they collide with anything. They can easily be shielded by a sheet of paper or the outer layer of a person's skin. An alpha particle has a large mass and two protons, two neutrons, and no electrons. Because it has two protons and no electrons, it is positively charged. When emitted from the nucleus, the positive charge causes the alpha particle to strip electrons from nearby atoms as it passes.



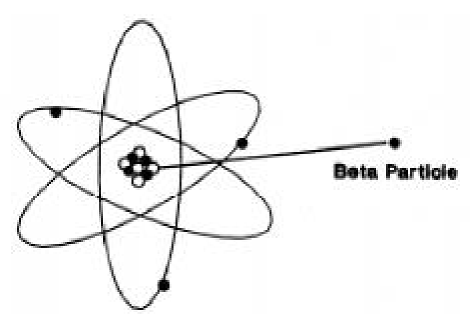
Alpha Radiation

Alpha particles are extremely hazardous to fire fighters because they can be inhaled and deposited in body tissues, where they can cause severe long-term health effects. Positive pressure SCBA is effective protection against inhaling alpha particles. These agents can affect the cells of the body in various ways, and each is capable of destroying cells.

Beta Particles

Beta particles are more energetic than alpha particles. They travel in the air for a distance of a few feet. Beta particles can pass through a sheet of paper but may be stopped by a sheet of aluminum foil or glass.

A beta particle has a small mass and is usually negatively charged. It is emitted from the nucleus of an atom with a charge of minus one. Beta radiation causes ionization by interfering with electrons in their orbits. Both have a negative charge, so the electrons are repelled when the beta particle passes.

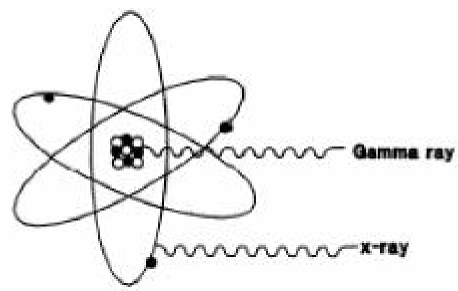


Beta Radiation

Beta particles can damage the skin or tissues of the eye. Internally, they can be extremely damaging if they concentrate in specific tissues.

Gamma Rays

Gamma rays (unlike alpha or beta particles) are waves of pure energy; they have no mass. They are emitted from the nucleus of an atom and travel at the speed of light (186,000 miles per second). Gamma radiation can be very penetrating and requires concrete, lead or steel to stop it.



Gamma Radiation

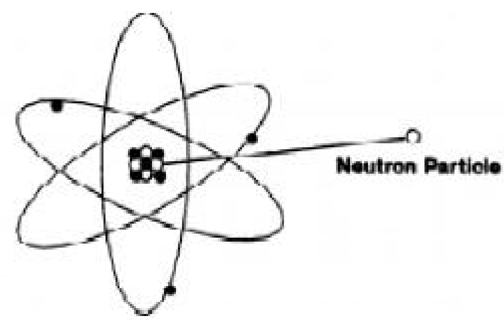
X-Rays

X-rays are essentially the same as gamma rays except that they are emitted from the electrons that orbit the atom's nucleus, rather than from the nucleus itself. Gamma rays and X-rays are also called **photons.** Because they have very high energy and penetrate deeply, gammas and X-rays can affect not only specific organs, but the surrounding tissues as well.

Gamma radiation and X-rays are electromagnetic waves or photons and have no electrical charge. The difference between the two is that gamma rays originate inside the nucleus and X-rays originate outside the nucleus. Both can ionize an atom by directly interacting with the electron.

Neutron Particles

Neutrons are particles normally contained in the nucleus of an atom. They can be released through certain manufacturing processes, such as nuclear fission (splitting an atomic nucleus).



Neutron Radiation

Neutrons are considerably larger than beta particles but have only one-fourth the mass of alpha particles. Because they can penetrate even thick lead shields, they can be extremely damaging to humans. However, neutron radiation is very rare since it is generally emitted only when atomic weapons are detonated.

EXPOSURES

Effects of Exposure

The effects of radiological exposures can be characterized two ways: as a result of **whole body exposure** or as a result of **local exposure**. These terms are discussed below.

Whole Body Exposure

Exposure of the entire body to a dose of 100 R or greater in a short time period (24 hours or less), results in signs and symptoms known as **acute radiation syndrome.** The radiation source in such cases is usually gamma or X-rays. Actual cases of unintentional whole-body radiation exposure have occurred only very rarely. Few symptoms are noted at doses under 100 R, but damage can be detected in white blood cells.

Doses greater than 100 R result in progressively more threatening consequences that tend to follow a predictable time course. Doses of 100 to 200 R usually cause nausea and vomiting within hours of the exposure. Typical results of laboratory tests include a decrease in certain blood components, especially white blood cells, within two days. This effect is important because white blood cells play a major role in the immune system.

At doses from 200 to 600 R, the most critical problem is maintaining sufficient levels of circulating blood cells. This dose range is life threatening, especially if no treatment is received. White blood cells are most severely affected.

At doses of 300 R or more, hair loss occurs after about two weeks.

With exposures between 600 and 1,000 R, chances for survival are decreased. Death may result from infection, hemorrhage, and other results of decreased bone marrow functioning, but may take months to occur.

At doses greater than 1,000 R, cells of the small intestine lining are damaged and do not recover, resulting in infections and loss of fluid and electrolytes through the wall of the intestine. Death occurs within days.

The Environmental Protection Agency (EPA) recommends dose limits for emergency workers in various situations. The rem dosage noted below reflects the Total Effective Dose Equivalent (TEDE) lifetime exposures.

rem	Condition
5	General monitoring (no life safety involved)
10	Protection of a large population
25	Life saving (once in lifetime)
>25	Life saving (authorization required)

Source: U.S. EPA

For exposures above 25 rem, responders must be made fully aware of the risks involved, and the person or agency in command must authorize the exposure in writing.

Local Exposure

The effects of partial body exposure to radiation depend on the dose and site of the exposure. Other organs frequently affected by local exposure include the skin and reproductive organs. Effects on bone marrow and the gastrointestinal system occur when these organs are the targets of the exposure. Signs and symptoms of exposure, such as nausea and decreased white blood cells and platelets, are also seen when radiation is used in the treatment of cancer.

The following photograph shows the right buttock of a man who had carried a 28-curie iridium radiography source in his back pocket for 45 minutes. When this photo was taken – about 31 days after exposure – the burn was 4" in diameter and about 1" deep.

Radiation burn from radiography source

Improper handling of gamma or beta sources or heavy exposure to X-ray, neutron, or other particle beams can result in radiation burns to the skin. These are classified like thermal burns – first, second, or third degree, depending on the extent of the injury. However, unlike thermal burns, they develop much more slowly, often taking days to become evident. Because of this, the cause of the burn is not always recognized.

Cancer and Radiation

Cancer is a major long-term health effect of ionizing radiation. The reasons for this effect are not yet fully understood, but are likely to be related to changes produced in the DNA, the genetic material of cells. These changes may involve several steps that take years to progress to the onset of cancer.

Many scientists who experimented with radiation at the turn of the century later developed skin cancer. This was the first link noticed between radiation exposure and cancer.

Other types of cancer are also thought to be associated with radiation exposure. Leukemia, a cancer affecting bone marrow, has been linked to several types of radiation exposure. Some risk for lung cancer has been attributed to radon gas, particularly among uranium mine workers.

Other types of cancer linked to radiation-exposed humans include bone (other than leukemia), breast, stomach, and thyroid. For example, workers who applied radium paint to watch dials ingested radium when they dabbed their paint brushes on their tongues. Radium is taken up by bone tissue. These workers have been shown to have higher than average rates of various bone cancers.

The following photograph shows two views of a right hand that belonged to a pioneer medical radiologist. The hand was amputated in 1932 and the radiologist died in 1933. Cancerous conditions like this were caused by repeated doses of radiation adding up to thousands of rems.

Other Hazards of Radioactive Materials

You should be aware of several multiple hazard situations involving radioactive materials. One of these is the presence of explosives or flammables with radioactive material. Radioactive material is forbidden from shipment with Class A explosives but may accompany other classes of explosives.

Also, many radioactive materials are shipped as compounds of acids or bases. Uranium hexafluoride (UF_6) is one example of an acidic radioactive material. Breached containers of this compound can release highly toxic and corrosive hydrogen fluoride gas.

The toxicity of this gas is far more hazardous than the radioactivity of the uranium, and emergency personnel should be alert to fumes, smoke, and irritating or noxious odors. Shipments of uranium hexafluoride must bear both RADIOACTIVE and CORROSIVE labels and placards.

Heavy elements such as uranium, thorium and plutonium may spontaneously ignite and burn when in finely divided metallic form. This will produce airborne radioactive material. Fire fighters should watch for smoking from these packages; although these elements are probably not shipped in this form.

Water-Sensitive Radioactive Materials

Some radiological materials are water-reactive. Uranium hexafluoride is probably the most common. For these materials, the chemical hazards are much more serious than the radiation hazards. Although these materials are shipped in protective overpacks, they may explode or react violently with fuels if the container is breached.

If you are responding to an incident that involves water-sensitive radioactive materials, keep these points in mind:

- Structural fire fighting gear will not protect you from contamination; only trained personnel in chemical protective clothing should respond.
- Use dry chemical, water spray, fog or foam on undamaged containers, but do not use water or foam if there is a release.

If a fire is not involved you may see a foaming residue or sense irritating vapors, indicating a release.

PROTECTING YOUR HEALTH AND SAFETY

In an emergency situation, you may know only that a material is radioactive without knowing which type of radiation is being emitted.

Limiting Exposure

You can minimize your exposure to any type of radiation by:

- Limiting the **time** that you are near the source of radiation
- Increasing the **distance** between yourself and the source
- **Shielding** yourself with appropriate protective clothing

Time

The shorter the time you are exposed to radiation, the less your exposure. Work quickly and efficiently; rotate teams to keep individual exposures to a minimum.

Distance

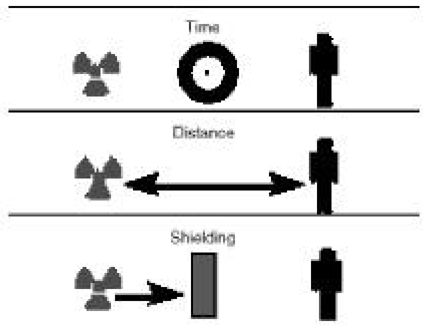
The farther you are from a source of radiation, the lower the dose you receive. If you must approach low level radioactive materials, do not touch them; use shovels or brooms and avoid physical contact.

Shielding

SCBA and bunker gear shields you from most alpha and beta radiation. Several inches of lead is necessary to shield you from gamma radiation. In the field, use clothing, vehicles, equipment, containers or natural barriers like hills, trees, and rocks to protect yourself from radiation exposure. However, be aware that your apparatus, depending on its profile and construction material, may not provide adequate shielding.

Shielding also includes covering the source itself. For example, you may be able to prevent exposure to alpha and some beta radiation if you cover the source with a drum or heavy material, such as a tarp.

Like other exposures, if your clothing or skin is contaminated with a radioactive substance, exposure will continue until you are decontaminated.



Hazardous materials incidents often place First Responders in uncontrolled and potentially hazardous environments. You may be exposed to a range of chemical, biological, and physical hazards. It makes sense, then, to monitor every responder's health through periodic medical examinations. Such examinations are designed to detect any changes in your health so that early treatment can prevent irreversible disease processes. These medical examinations are usually performed within a medical surveillance program and monitored by a licensed health care practitioner with expertise in occupational health.

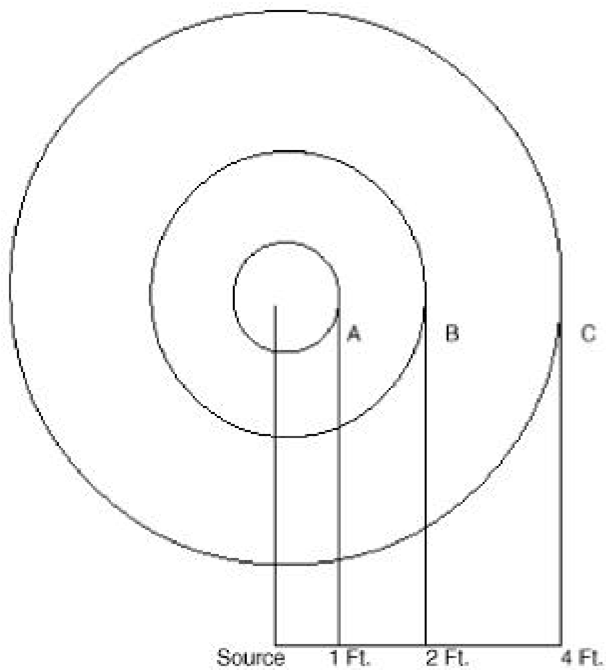
Inverse Square Law

The inverse square law is based on the principle that the farther a person is from a source of radiation, the lower the dose will be. By measuring the radiation exposure rate at a given distance from a source, then doubling the distance from the source, the intensity of the radiation is reduced by one-fourth. For example, radiation that measures 8mR/hr at 2 feet from a source would measure only 2mR/hr at 4 feet from the source.

Conversely, when the distance from the source of radiation is reduced by half–for example, from 2 feet to 1 foot–the exposure rate increases four times, from 8mR/hr to 32 mR/hr. The diagram on the following page illustrates this principle.

The inverse square law is valid only for small point sources such as those used in radiography. It does not apply in accident situations where radioactive materials are released and scattered.

Exposure Rate At Point	Example
A = 4x B = x C = 1/4x	32 mR/hr 8 mR/hr 2 mR/hr



The Inverse Square Law

The Inverse Square Law means that as distance from a source *increases*, the rate of exposure *decreases*; essentially, the *further* you are, the *safer* you are.

PPE and Radiation

Clothing that covers skin also offers protection from some forms of radiation. However, it will not keep you from becoming exposed. A fire fighter dressed in full structural fire fighting clothing (helmet, SCBA, coat, pants, boots and gloves) is well protected from surface contamination. If you should become contaminated by a liquid or solid (not airborne) hazardous material, taking off your outer clothing should remove most of the contamination.

Airborne contamination is more dangerous. If a radioactive contaminant enters your body through a cut in your skin, or if you inhale radioactive particles, the material will remain inside your body and continue to expose the surrounding tissue. The best protection against internal contamination is SCBA. Always wear your SCBA when airborne radiation (or any other airborne hazard, for that matter) is suspected.

Remember that alpha particles will not penetrate the skin, so your regular protective clothing will offer sufficient skin protection. However, alpha radiation can cause very serious problems if it is inhaled.

Although beta radiation can be stopped by a thin piece of metal, structural fire fighting gear (with a duck shell and Nomex liner) offers little protection. Furthermore, inhalation of particles can cause extensive damage.

Gamma rays can penetrate lead, so your fire fighting gear will not keep you from exposure to this type of radiation.